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Distinctive morphological features of *Skolithos linearis* from the Eocene of the Aínsa-Jaca Basin (South-Central Pyrenees).

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RESUMEN – En el presente artículo, se describen unas capas de arenisca con una gran cantidad de *Skolithos linearis* del Eoceno superior de Aguilar, en la cuenca de Aínsa-Jaca de los Pirineos Centrales. *Skolithos* es un icnogénero caracterizado por galerías cilíndricas verticales y no ramificadas. Etológicamente considerada como vivienda permanente o semi-permanente (i.e. Domichnia), puede ser produccida por diferentes tipos de animales, habitualmente por anélidos pero también por foronídeos o crustáceos. A pesar de ser común durante todo el Fanerozoico, es una traza poco citada en el Eoceno. La abundancia de *Skolithos* es indicativa de un paleoambiente marino poco profundo. El estudio detallado de los icnofósiles de este yacimiento muestra unas caracteristicas especiales y uniformes en todos ellos, como poseer un gran hueco de entrada y su oblicuidad multidireccional con respecto a la vertical. Estas caracteristicas son analizadas y discutidas.

ABSTRACT – A sandstone bed with abundant *Skolithos linearis* burrows is described from the Late Eocene of Aguilar, Aínsa-Jaca Basin, (South-Central Pyrenees). Ichnogenus *Skolithos* is a simple structure consisting of vertical and unbranched cilindrical burrows. It's considered as a dwelling structure (i.e. Domichnia) and as a facies-crossing trace fossil. Although annelids have been proposed as the most likely tracemakers, phoronids and crustaceans have been not discarded. Despite being common in all Phanerozoic, these traces are not-so-common during the Eocene. The presence of abundant *Skolithos* indicates a shallow marine paleoenvironment. The detailed study of the ichnofossils in this outcrop shows some special and uniform characteristics, such as having a large apertural diameter and their multidirectional obliquity. These features are analyzed and discussed.

KEY WORDS – *Skolithos*, trace fossils, Eocene, Southern Pyrenees

INTRODUCTION

Ichnogenus *Skolithos* (Haldeman, 1840), is a very common ichnofossil from the late Precambrian to the Quaternary, because many species of filter feeders or deposit feeders can produce vertical dwelling shafts defined as *Skolithos*. Research on recent similar vertical structures indicates that they can be produced by some sipunculan, phoronid and polychaete worms, eel-like fishes and also some actinian, anemones, insects and spiders (Bromley, 1996).

But while there are numerous descriptions of findings of this ichnofossil in the Paleozoic and Mesozoic eras (e.g.: Desjardins *et al.,* 2010: Cambrian and Ordovician; Vinn & Wilson, 2013: Silurian; Bromley & Uchman, 2003: Jurassic; Vossler & Pemberton, 1988: Cretaceous), its presence is little documented in the Cenozoic (e.g.: Belaustegui, 2016: Pliocene; Pemberton & Jones, 1988: Pleistocene). In Eocene turbidite systems like the one of the outcrop described in this paper, *Skolithos* is only mentioned in four of the about 33 ichnologycal research papers consulted by the author (Crimes, 1977; Tunis & Uchman 1996 a,b; Heard, 2007), while other ichnogenera associated with the *Skolithos* ichnofacies (Seilacher, 1967b), as *Ophiomorpha*, *Arenicolites*, *Thalassinoides* and *Diplocraterion* are widely cited (e.g. Buatois *et al.,* 2001; Villegas-Martín et al., 2014; Starek & Simo, 2015). It should be noted that *Skolithos*, in addition to being present in the ichnofacies named for it, is also found in other trace fossil assemblages such as Scoyenia ichnofacies.

The most probable cause of the *Skolithos* decrease in the Cenozoic, is related by some authors with the replazament of *Skolithos* by *Ophiomorpha*, as a dominant vertical burrow structures due to the Mesozoic radiation of the *Ophiomorpha* producer, decapods crustaceans (Carmona *et al*., 2004).

It is described an outcrop with an abundant quantity of *Skolithos* burrows. All the speciments found in this outcrop have particular morphological characteristics that differ from the usual description of the *Skolithos* ichnogenus. The aim of this paper is to describe in detail these burrows, focusing on these differential features, analyzing and discussing their possible origin.

GEOGRAPHIC LOCATION AND GEOLOGY SETTING

Locality. Aguilar is a small village located on the western slope of the Boltaña anticline in the Central-South Pyrenees. It belongs to the middle sector of the Ainsa-Jaca Basin, in the Eocene Hecho Group turbidite system (fig. 1).

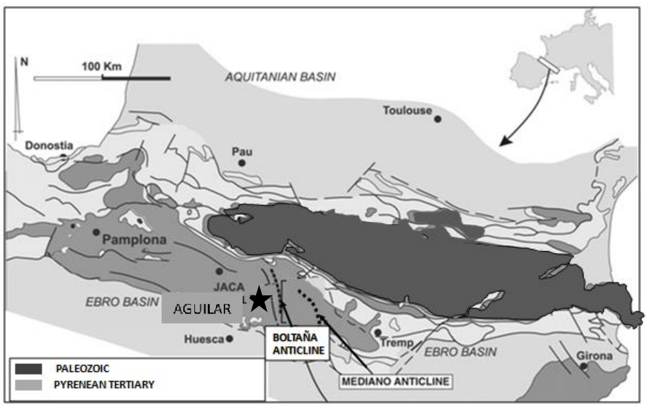


Figure 1: Simplified geological map of the South-Central Pyrenees showing the situation of Aguilar (Modified of Labourdette & Jones 2007).

Geology of the Hecho Group turbidite system area has been widely studied (Seguret, 1970; Puigdefabregas 1975; Mutti *et al.,* 1972, 1977, 1985, 1988; Remacha *et al*., 2003, 2005; Barnolas, 2001). The local Eocene succesion can be divided into two main basins, the inner basin, extending from Tremp to Pamplona, developed between late Paleocene and late middle Eocene times and the outer basin (late middle Eocene and Priabonian) developed following a major phase of tectonic deformation that resulted in a southward shifting of the basin axis (Mutti *et al.,* 1985). Is in this Late Eocene outer bassin that is located Aguilar outcrop.

The geology setting of the Aguilar surrounding is accurately described by Puigdefabregas (1975), in his work on the Jaca sedimentary basin: "*The profiles of the Ara Valley show the situation of nummulitic levels that succeeded marly-turbiditic series. These strata suffer a strong condensation in the vicinity of the flank W of the Boltaña anticline. In the town of Aguilar they are reduced to a limestone level constituted all by nummulites discordant on the anticline limb with internal discordance as we move away towards the W. and finally with a discordance that places the red formation of Campodarbe on all the previous levels, surrounding the spectacular paleorelief of Aguilar"* (fig.2).

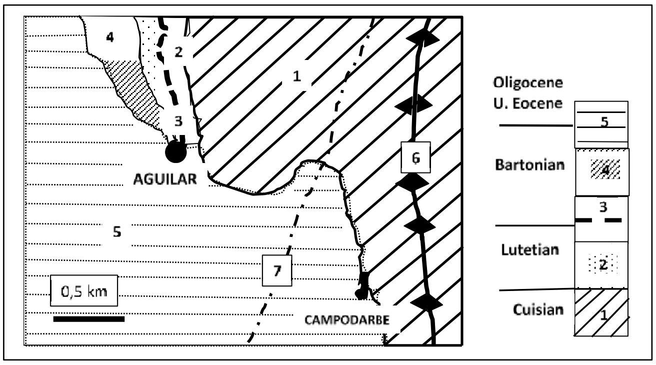


Figure 2: Geological detail of the Aguilar outcrop. **1)** Boltaña anticline limestone, **2)** Marls with nummulite levels, **3)** Aguilar nummulites bank. (fig . 4), 4) Deltaic compound, 5) Campodarbe continental formation, 6) Boltaña anticline , 7) Morillo San Pietro fault. (Modified from Puigdefabregas , 1975)

In the aforesaid village, at the foot of its church (Ermita de San Miguel) there is a sandstone bed with a large number of *Skolithos* trace fossils (fig. 3) which are those studied in this paper.

In the same town of Aguilar about 200m. east, outcrops a massive bed (fig. 4) of nummulites identified as *Nummulites biedai* (Schaub), instead *Nummulites perforatus* (de Monfort) and *Nummulites millecaput* (Boubee), cited in Puigdefabregas work.

Nummulites biedai usually defines a paleoenvironment with a facies corresponding to a inner platform with high-energy hydrodynamic regime (Papazzoni & Sirotti, 1995), corresponding to the Bartonian, Upper Eocene. However, the arrangement and structures observed in the field do not clearly determine a high energy structure (see the next Lithology paragraph).

Figure 3: *Skolithos* burrows in the vicinity of the Aguilar Church.

There is also a large amount of published works on the ichnology of the Hecho Group turbidite system, highlighting the extensive monographs of Uchman (2001) and Heard & Pickering (2007). But, as mentioned above, there are very few quotations from *Skolithos* findings. Only Heard & Pickering (2007) describe a specimen found in the eastern part of the Ainsa-Jaca basin, far from the Aguilar town, that corresponds to the upper slope sand-stone filled gully

Figure 4: Masive bed of *Nummulites biedai,* in the vicinity of Aguilar.

Lithology. Yellow sandstone stratified in subhorizontal or low-angle decimetrical strata, with internal low-angle cross planar sets. Particles are fine to medium size, angular, composed by quartz, limestone and a small percentage of metamorphic siliceous grain particles, so it would be included as litharenite with well-developed calcareous cementing material.

Regarding the sedimentation environment, it can be affirmed that they would be of fluvial or distal fan-delta origin. Grain shape suggests short distance transportation to their depositional site. Depositional environment was a marine transition area but without subsequent marine influence (lack of bioclasts and grain reworking).

Two samples of this sandstone rocks with *Skolithos* burrows were collected at this outcrop. Specimens are figured in Plate 1, and deposited in the Museo Paleontológico de Sobrarbe, with identification numbers 18/01 and 18/02.

Systematic Ichnology

Ichnogenus : ***Skolithos*** Haldeman, 1840
Type ichnospecies: ***Fucoides*? (*Skolithos*) *linearis*** Haldeman, 1840

Skolithos ichnogenus has been revised repeatedly, probably because in its first description Haldeman, (1840) did not define a holotype of the type ichnospecies *Skolithos linearis* or published its illustration. Recently Knaust *et al.,* (2018) designated a valid neotype of *Skolithos linearis* based on the same type locality described by Haldeman. Previously, Alpert (1974) made a systematic review of the ichnogenus in which established only 5 valid species of the 35 existing until then. Schlirf, (2000) and Schlirf & Uchman (2005) redefined the diagnosis of *Skolithos* and also studied the synonymy with other ichnogenus consisting of vertical burrows, as *Monocraterion* or *Sabellarifex.*

Skolithos linearis Haldeman, 1840

Diagnosis (redefined after Knaust *et al.,* 2018) Vertical to slightly inclined, cylindrical to sub-cylindrical, straight to slightly curved, unbranched burrow, more or less distinctly lined, with homogeneous fill and very high length-to-diameter ratio.

Description- Oblique unbranched burrows, 3 to 9 mm. in diameter (in few burrows up to 20 mm., Plate 1.7), inclination between 4° and 10° from the vertical, diameter and inclination are maintained along the entire length of burrow, preserved in full relief. Top apertures are circular, cylindrical cup-shaped, and having a larger diameter (8 to 18 mm.) than the rest of the burrow in the first millimeters. Total lenght is difficult to determine because some of the specimens pass across the layer, which in the case of specimen 18/01 is 65 mm. Walls annulated (Plate 1_6).

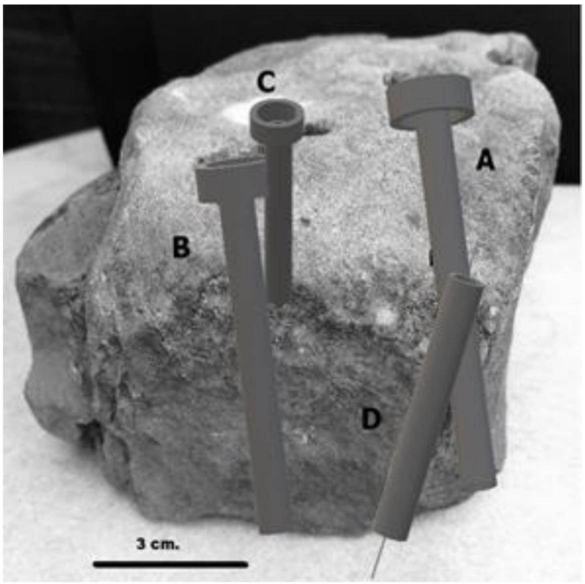
Discussion- *Skolithos linearis* of the Aguilar bed have two distinctive features: A larger cylindrical cup-shaped aperture and the oblique burrow, which are common in all specimens of the bed.

Aperture: While the diameter of the burrows is between 3 and 9 mm. being constant in each of the individual burrows, and therefore adapting to measurements common to the *Skolithos linearis*, the diameter of the entrance reaches up to 18 mm. Burrow entrance has no funnel-shaped, but in the first mm. the burrow diameter increases, also cylindrical, slightly cup-shaped. Larger apertures are common in *Skolithos*, usually funnel-shaped, but in cylindrical ones, while the ratio between the diameter of the opening and that of the rest of the burrow is abouth 17% in other outcrops (Vinn & Wilson, 2013), in the case of Aguilar reaches 200%.

The increase in diameter is probably due to the action of the crown of tentacles or feeding radioles of the producer, like phoronids and tentacular-crowned polychaetes. Where gregarious behaviour is indicated by the high densities of *Skolithos*, a mucous net or tentacular crown is the most likely feeding implement (Barnes 1980; Pemberton & Frey 1984b). Long burrows in beds of planar and trough cross stratified sandstone indicate that the animal was able to retract its feeding apparatus and retreat deep into its burrow during times of turbulence and scour (Desjardins *et al*., 2010). Reconstructions of a hypothetical organism making sedimentary structures associated with the *Skolithos linearis* tubes (Sundberg, 1983) shows a suspension-feeding organism during a period of low turbidity with tentacles fully extended to gather food. During times of high turbidity and sedimentation, the worm retracted into its burrow with its tentacles folded inwards. Both phoronids and polychaetes retract vertically into their burrows by contraction of the body. Phoronids during retraction fold their tentacles inward (Hyman, 1959) which would create a plug in the tube to keep sediment out. When quiescent or periods of lower turbidity occurred the organism would emerge from its burrow. Shape and diameter increase are shown in the mold of the opening of burrow C, specimen 18/01, Plate 1_4.

Burrow inclination: Burrows of this bed are neither perpendicular to the horizontal line nor parallel to each other how this ichnogenus is usually defined (Häntzchel, 1975, Vinn & Wilson 2013). All the specimens studied have an inclination between 4º and 10º from the vertical, which are maintained along the entire length of burrow. Burrows are oblique in different directions.

While the cause of the inclination of the burrows is related to the morphology of the producer (some of the Polychaete worms and other annelids, spiders or eel-like fishes made inclinated burrows), digging in different directions is related to the occupation of space, specially in denselly populated areas, to avoid penetrate into neighboring burrows as it occurs in other vertical digging trace fossils.. As shown in Fig. 5 of specimen 18/01, burrows A and B, both crossing the layer, tend to occupy space in their directions, while C moves in the opposite direction to avoid intersecting with the others. Burrow C is smaller in diameter and length than A and B, indicating the activity of a younger producer, whose activity was subsequently started.



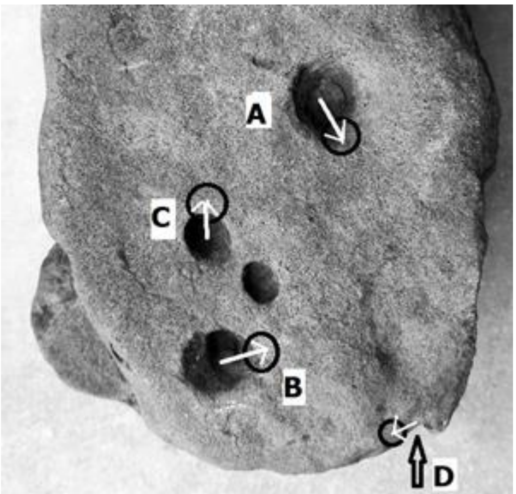


Figure 5: Reconstruction of *Skolithos* burrows, showing their different directions in specimen 18/01 (3D sketch and upper view). Not to scale.

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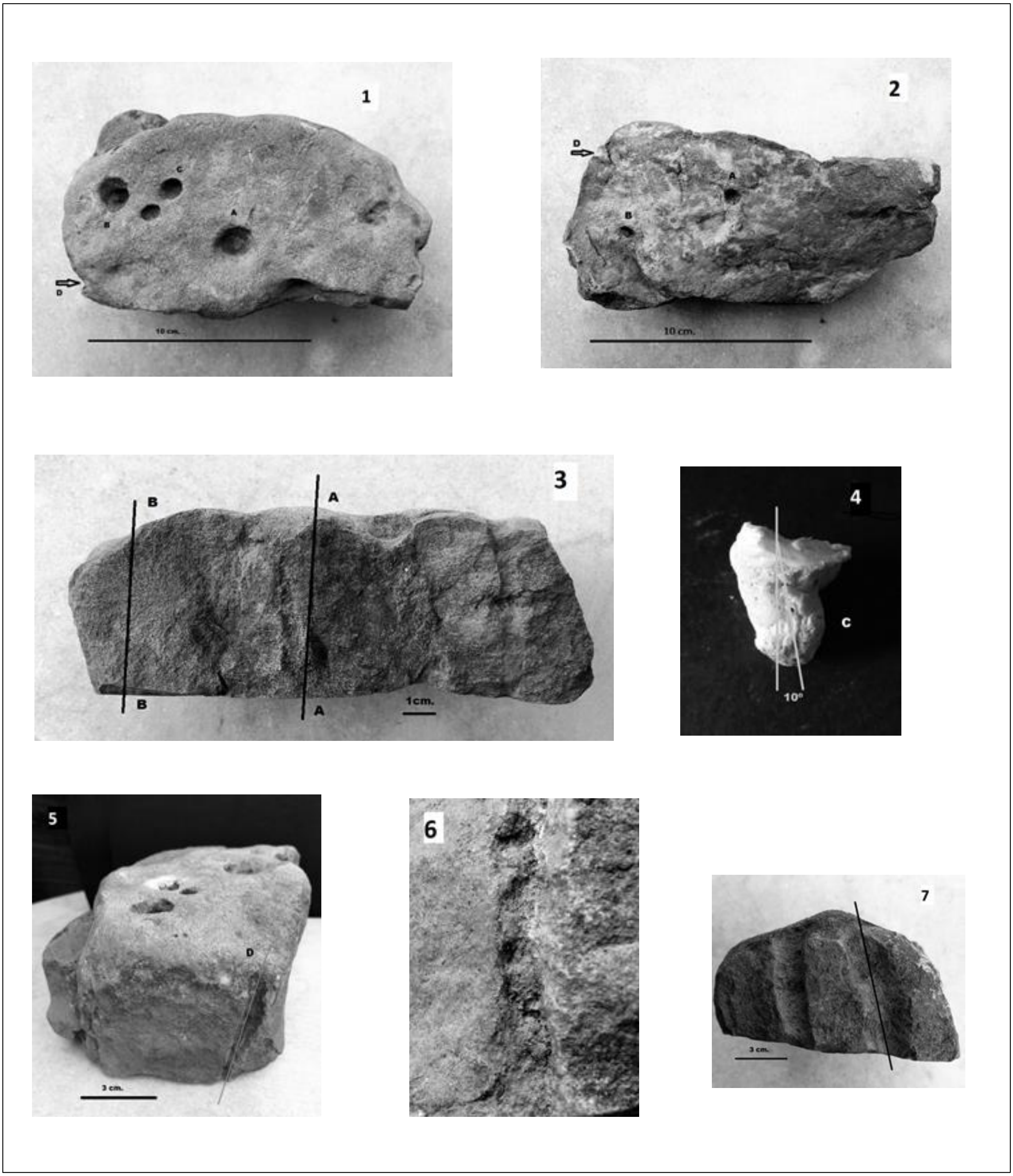

Plate 1: 1) Top view of specimen 18/01; 2) Reverse side of specimen 18/01 showing crossing layer *Skolithos* burrows A,B and D; 3) Side view of specimen 18/01, showing inclination of burrows A and B; 4) Mold of burrow C top entrance, showing diameter increase and inclination; 5) Side view of specimen 18/01 showing burrow D; 6) Detail of annulated wall of burrow D; 7) Side view of specimen 18/02.